THE EFFECTIVENESS OF AIRBAGS IN AUSTRALIA AS DETERMINED BY IN-DEPTH CRASH INJURY RESEARCH

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ABSTRACT

This study presents some results from a case-control study of crashed vehicles equipped with Australian airbag technology (Supplementary Restraint Systems). Vehicles were inspected and occupants interviewed according to the National Accident Sampling System (NASS). Data were available for 383 belted drivers involved in frontal crashes including 253 drivers in airbag-equipped vehicles and 130 drivers in non-airbag vehicles. The analysis revealed reductions in the numbers of injuries to the head, face chest and neck in the airbag-equipped vehicles although the numbers of upper extremity injuries increased. At higher injury severities (AIS2+) reductions were also observed in injuries to the head, face, neck and chest. Further analysis using Harm as an outcome measure found that the mean Harm per driver (in terms of $AUD) were 60% greater in the non-airbag vehicles compared with the airbag-equipped vehicles. Thus airbags in Australia would appear to offer a significant saving in terms of costs to society.

In general, the main conclusion from the study was that the results offer a strong indication that the Australian Design Rule (ADR) 69 requirement has been successful at addressing some of the outstanding issues that remain for injury prevention for drivers involved in frontal impacts.

INTRODUCTION

In 1989, the Australian Federal Office of Road Safety (FORS) embarked upon a comprehensive 3 year crash testing and standards development programme. The aim of this programme was to examine passenger car occupant injuries in frontal crashes and to develop appropriate countermeasures to minimise the level and type of injuries occurring.

The end result of the programme was the development of a dynamic frontal crash protection standard – Australian Design Rule (ADR) 69[1]. This performance-based ADR requires vehicle manufacturers to design their Australian passenger models to meet specific injury level criteria. The type of vehicle design changes incorporated to meet the new ADR requirements were left to individual manufacturers.

The ADR 69 took effect on 1 July 1995 with design changes in response to the ADR being quickly implemented in the Australian market place. This was clearly demonstrated by the increased availability of airbags across new model ranges. Although airbags were not the only option open to vehicle manufacturers to meet ADR 69 requirements, the majority of vehicle manufacturers demonstrated a strong preference for them. Currently all new manufactured Australian passenger cars have at least the driver's airbag fitted as a standard restraint system to supplement the high seat-belt wearing rate in Australia.

Background to Current Study

In order to evaluate the impact of ADR 69 on passenger car occupant injuries, the Federal Office of Road Safety perceived the need for a programme to examine actual crash data. Therefore a programme was developed that would allow occupant injuries to be compared in a representative sample of pre- and post-ADR 69 passenger vehicles. In Australia, airbags are seen predominantly as Supplementary Restraint Systems (SRS's) to be used in conjunction with the wearing of the seat belt. In general, the seat belt is designed to prevent the occupant from having harsh contacts with interior surfaces of the vehicles whilst the airbag has positive internal pressures which can exert distributed restraining forces over the head and face. Furthermore, the airbag can act on a wider body area including the chest and head, thus minimising the body articulations, which cause injury. Optimisation of the restraint system with airbags go together in maximising occupant safety to reduce injury outcomes during a frontal crash. One Australian study using computer simulation methods found that optimising the restraint systems and having an airbag fitted would reduce injury outcomes by 9% [2]. Optimising the airbag resulted in 17% injury outcome reduction but in harness the optimised restraint systems plus an optimised airbag increased this to a 33% reduction. These outcomes were based on the ADR 69 specifications for the Hybrid III anthropomorphic dummy in Table 1.

Table 1.
Full frontal test criteria

	Performance Criteria
Head	HIC shall not exceed 1000 over 36ms
Sternum	Compression not to exceed 76.2mm
Thorax	Chest deceleration not to exceed 60g
Femur	Axial force not to exceed 10kN
Barrier	To conform to SAE document J850
Speed	48.3km/h (30mph)

Field Studies of Supplementary Restraint System (SRS) Airbag Deployments

There have been a number of studies conducted both in Europe and Australasia, which have examined predominantly field SRS airbag performance. In Germany, Otte (1995) [3]

found that injuries that occurred in airbag crashes were mostly minor although there were some occupants who sustained more serious injuries (as measured by the AIS scale).

The main injuries sustained were haematomas to the thorax, nosebleeds and burns to the forearm. However, he expressed concern about the number of cervical distortions occurring in the sample of frontal impacts and concluded that the airbag may induce a powerful 'hyper-extension' movement of the head and cervical spine.

Langwieder et al (1996) [4] looked at 249 accidents in airbag-equipped cars. They observed a significant reduction in severe and fatal injuries to the belted and airbag-protected drivers.

They also found that the main types of AIS2+ injury sustained by drivers with airbags were injuries to the extremities especially the feet. One further interesting finding in the study was that although neck injuries occurred to both belted and airbag-protected drivers and belted-only drivers, they were less likely to occur in the first group.

Morris et al (1996) [5] examined injury patterns in European and Japanese airbag-deployed vehicles. In all 186 frontal crashes were examined. The majority of the drivers in the crashes sustained AIS 1 injuries with the head/face being the most common body region injured. Some AIS2+ injuries occurred but these almost always occurred when the optimum deployment conditions were compromised in some way. The most common site of AIS2+ injuries in the study was the lower limb although several AIS2+ upper limb injuries were observed.

Morris et al (1998) [6] examined data from four countries and studied injury outcomes in crashes in which airbags deployed. The data showed that in the US, Canada and Australia, airbags led to a general overall reduction in AIS2+ injuries. In the study, German data was only available on the head, chest, abdomen and lower limb and benefits were found for head and abdomen but dis-benefits were found in the chest and lower limbs. US benefits in head and chest were relatively small which were suggested to be due to a low threshold for deployment unlike in Europe and Australia where deployments occurred at higher threshold. One unexpected finding was that lower limb injuries increased to the seat-belt and airbag-protected drivers compared to the seat-belt protected only drivers.

Lenard et al (1998) [7] studied the injury distributions between a sample of airbag-deployed vehicles in frontal crashes and a larger sample of non-airbag equipped vehicles in frontal crashes in the UK. They found that airbag-equipped vehicles had relatively fewer head injuries and relatively more arm injuries.

Deery et al (1999) [8] examined a group of 140 belted drivers involved in frontal impacts of which 71 were involved in crashes in which the airbag had deployed and 69 were involved in crashes with vehicles not fitted with airbags. Their analyses revealed significant reductions in the cost of injury and a strong indication of a reduction in overall injury severity among the airbag cases. Indications of airbag benefits were also found in terms of a reduction in the probability of sustaining a moderate and severe injury. Some evidence was found for an increase in minor injuries among the airbag cases. They concluded that as expected, airbag technology seemed to be reducing head, face and chest injuries, particularly those of at least a moderate severity.

Methodology

The data in this study were obtained from a sample of crashes that were investigated as part of an on-going study of driver injury and vehicle crash performance by the Accident Research Centre at Monash University. This study examines injuries that were sustained by a sample of drivers involved in frontal impacts in which the Principal Direction of Force (PDoF) was within 60-degrees of head-on. Vehicles were examined at recovery-garages, scrap-yards and panel-beating shops in Victoria, New South Wales, Queensland and Tasmania (depending on accident location) within a few days of the accident. An inspection was performed on each vehicle in accordance with the US National Accident Sampling System (NASS) procedure for retrospective examination of crash-damaged vehicles. Only drivers who wore their seat-belts were included in the study. Determination of seat-belt usage was achieved with a high degree of certainty.

To assess collision severity in this study, Delta-V was calculated where appropriate. Analyses were made to ensure that the collision severity in both airbag-equipped and non-airbag equipped vehicles did not differ significantly.

This study used a “vehicle based” entry criterion. Minimum criteria applied in the case of each vehicle was that it sustained sufficient damage in the crash to warrant a tow-away by a recovery truck from the scene of the crash. A case-control method was also applied in the study. This involved comparisons of vehicle models that were introduced either before or after the ADR69 legislation. The intention was that the study would sample cases with and without airbags in order to compare the injury outcomes of the occupants of these two vehicle populations.

Ethical considerations demanded that the vehicle was included in the study only if the owner and occupants of the vehicle and the repair shop or salvage yard agreed to participate in the study.

Injury data were gathered on each consenting driver known to have been injured in the collision. This was achieved from an inspection of medical and coronial records of those seriously injured or killed or from a structured telephone interview by a trained nurse for those not requiring hospital treatment. In the case of seriously injured occupants, the casualty notes for the occupant were obtained from the Emergency department of the relevant hospital. When the occupants were fatally injured, post-mortem reports were obtained from the Coroner's Office.

Harm in this study is defined as a metric for quantifying injury costs from road trauma involving both a frequency and a unit cost component. In its most general form, it is used as a measure of the total cost of the road trauma. Harm can also be broken down by type of road user, body region injured and severity of the injury sustained.

Cases were selected using a baseline curb weight between 1000kgs and 2000kgs and a delta-V distribution (where calculable between 10 and 65kph. A total of 383 belted drivers involved in a crash were included for analysis. There were 253 belted drivers involved in crashes where the airbag deployed and 130 belted drivers involved in crashes where an airbag was not equipped or not deployed.

There were no significant differences in occupant characteristics (age, weight, sex and height), Table 2 or crash severity (as measured by delta-V) between the airbag cases and non-airbag cases.

Table 2.
Characteristics for belted drivers in airbag and non-airbag frontal crashes

Mean	Airbag cases (n=253)	Non-airbag cases (n=130)
Sex	71% males 29% females	66% males 34% females
Age	39 years (range 17-80 years)	40 years (range 17-81 years)
Height	174 cm (range 152-193cm)	174 cm (range 125-201 cm)
Weight	77 kg (range 45-175 kg)	77kg (range 48-120 kg)

The mean delta-V for the airbag cases was 33kph and non-airbag cases was 37kph ($p=0.20$, independent 2 tailed t test). Having established that the two sample groups were matched as far as was practical, it was hypothesised that any differences in injury outcomes in this study could be attributed to the effects of the airbag. Figure 1 gives the distribution of crashes in terms of collision severity.

Injury outcomes

The first analysis in this study demonstrates differences in injury outcomes between the two groups of drivers. Figure 2 shows this analysis.

Of interest is that there was a significant reduction in neck injuries ($\chi^2 = 7.2$, df=1, $p<0.007$) and a trend in the reduction of head injuries in the airbag group ($\chi^2 = 3.2$, df =1, p=<0.07).

However it was noted that significantly higher numbers of upper extremity injuries occurred within the airbag group compared to the non airbag group ($\chi^2 = 15.54$, df =1, $p<0.001$).

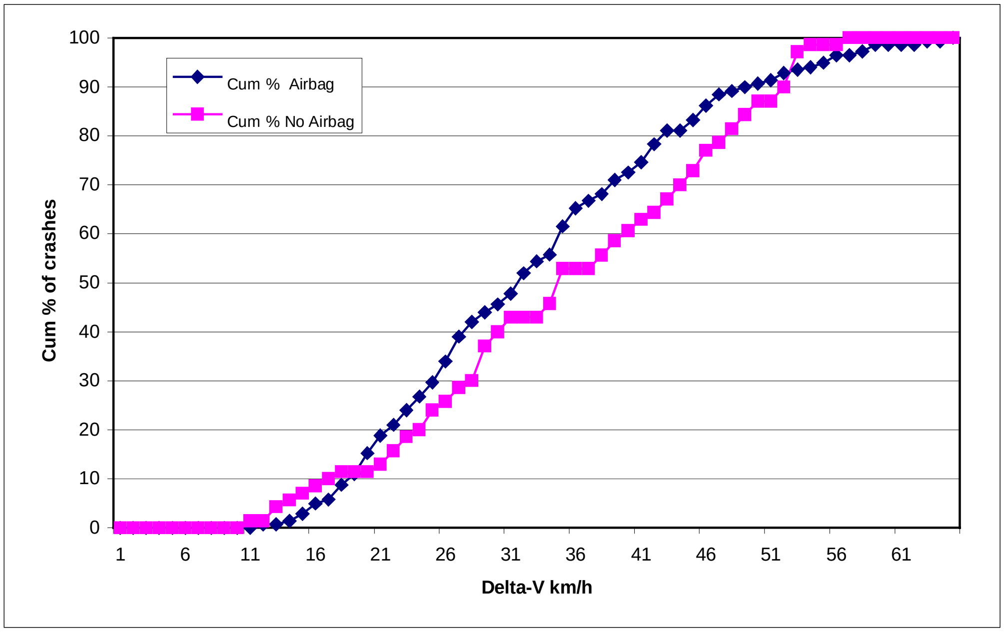
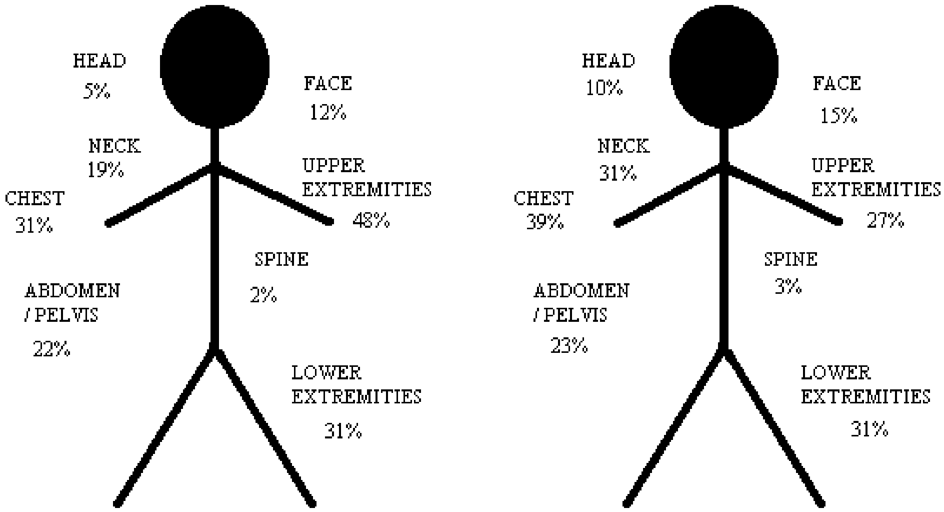


Figure 1.

Delta-V distribution for airbag and non-airbag cases.

The reduction in head injury rates is an intuitive finding since the airbags were originally designed to prevent contact between the head and the steering wheel. However, the reduction in neck injury rates was not anticipated but this result offers some insight into neck injury prevention generally and this is discussed in more detail later in this study.



Airbag group (n=253)

Non airbag group (n=130)

Figure 2.

Distribution of all injuries for belted drivers

Other trends in injury reductions were observed, particularly to the face and the chest. Therefore, whilst it cannot be stated with certainty that airbags are significantly reducing injuries to most body regions, there are definite injury reductions to the targeted body regions. Table 3 shows the results of statistical comparison of injured body regions in airbag and non-airbag cases.

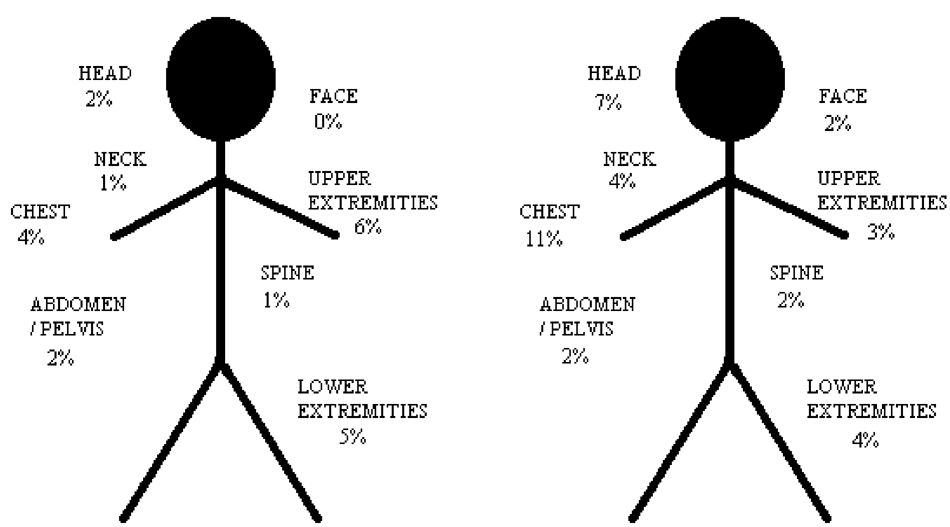
Table 3.
All injuries to body regions for belted drivers

Body region	Airbag cases (n=253)	Non airbag cases (n=130)	Significance
Head	5%	10%	<0.07
Face	12%	15%	ns
Neck	19%	31%	<0.007*
Chest	31%	39%	ns
Abdomen /pelvis	22%	23%	ns
Spine	2%	3%	ns
Upper extremity	48%	27%	<0.001*
Lower extremity	31%	31%	ns

* Chi squared test

For injuries sustained at the AIS2+ level there was a significant reduction in head and chest injuries to belted drivers in the airbag group (χ^2 5.8, df 1, p<0.02; and χ^2 5.97, df1, p<0.01). It was also found that neck injuries at this level were also lower in the airbag group compared to the non-airbag group (p.05, Fishers exact test). It should be observed that higher numbers of upper extremity injuries at the AIS2+ level were observed in the airbag group.

Figure 3 shows the distribution of injuries at the AIS2+ level to both drivers in the airbag and the non-airbag groups whilst table 4 shows statistical comparison of these results.



Airbag group (n=253) Non airbag group (n=130)

Figure 3.

Distribution of AIS2+ injuries for belted drivers

Table 4.
AIS2+ injuries to body regions for belted drivers

Body region	Airbag cases (n=253)	Non airbag cases (n=130)	Significance
Head	2%	7%	<0.02*
Face	0%	2%	ns
Neck	1%	4%	<0.05**
Chest	4%	11%	<0.01*
Abdomen /pelvis	2%	2%	ns
Spine	1%	2%	ns
Upper extremity	6%	3%	ns
Lower extremity	5%	4%	ns

* Chi squared test ** Fishers exact test

The non-significant number of upper extremity injuries sustained at the AIS2+ level would indicate that drivers in the airbag group are sustaining numerous minor injuries to this body region.

Figure 4 shows the MAIS injury Distribution for the two groups of drivers.

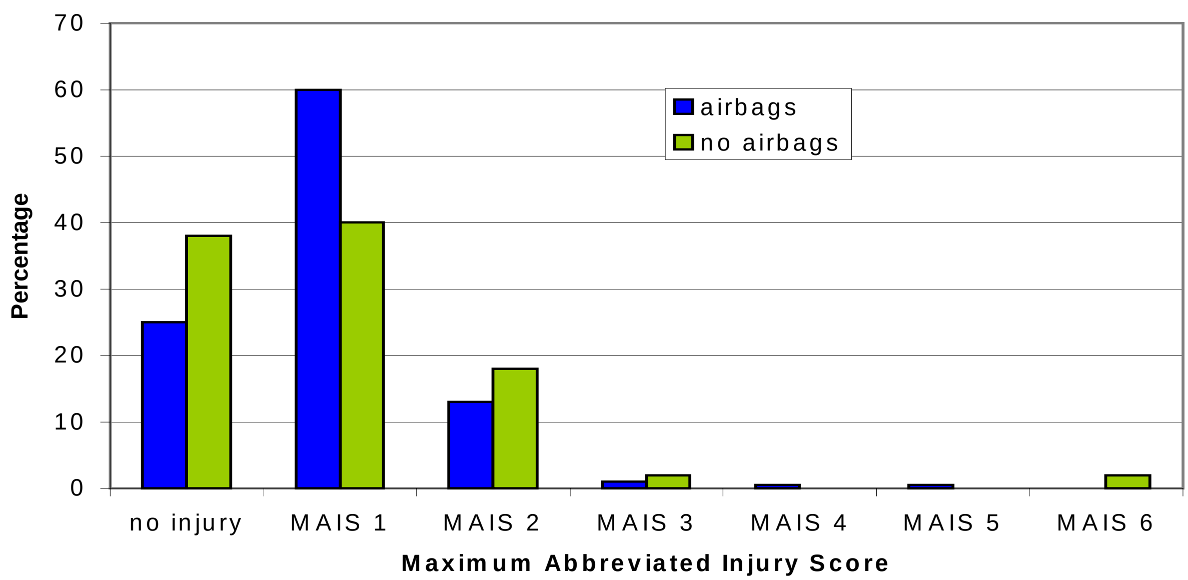


Figure 4.

MAIS for all belted drivers

As can be seen from figure 4, drivers in the airbag group were more likely to sustain injuries at the MAIS 1 injury level compared with the non-airbag group. Furthermore, drivers in the non-airbag group were more likely to sustain injuries at the MAIS 2 & 3 level compared to the non-airbag group. A very small percentage of MAIS 6 injuries were observed in the non-airbag group but these were not observed in the airbag group.

Injury Severity Score (ISS) and Harm Analysis

The ISS scores are presented in Tables 5 and 6 for all belted drivers involved in a crash (n=383) and for those belted drivers injured in the crash (n=270). When the mean ISS scores for all drivers are compared, the differences in terms of ISS are not significant although the mean Harm sustained by drivers in the non-airbag group is higher. However, when comparing between only those drivers who are injured, there is a significant difference in the mean ISS scores between the airbag and non-airbag group (independent t-test). This could be explained in part by greater numbers of drivers in the non-airbag group sustaining injuries particularly at the AIS 2 level.

Table 5.
Mean injury severity score and Harm for all belted drivers

Belted drivers	Airbag group	No airbag
Number of cases	253	130
Mean ISS	10.4	9.1
Mean Harm ($ 000s)	10.1	16.3

Table 6.
Mean injury severity score and Harm for injured belted drivers

Belted drivers	Airbag group	No airbag
Number of cases	190	80
Mean ISS	2.35	4.9
Mean Harm ($ 000s)	13.4	26.4

Injury Contact Sources

Contact sources for all injuries and AIS 2+ injuries were determined and grouped accordingly. The main contact sources for injury to both groups were the seat belts, steering assembly, instrument panels, deceleration forces and airbags for the airbag group (Table 7).

There were no real significant differences between the two groups in terms of contact source for their injuries. A trend in fewer steering column contacts was noted in the airbag group (χ^2 3.63, df 1, p=0.06). Furthermore, there were obviously several injuries sustained in the airbag group due to contact with the airbag itself. It was interesting to observe that the non-airbag group sustained higher numbers of AIS2+ injuries due to interaction with the seat-belt. This would suggest that the airbag does offer additional driver restraint and distribution of crash forces over wider area than the head and face alone.

An interesting observation in the airbag group is that whilst there were several injuries attributable to interaction with the airbag (almost always minor abrasions and ‘burn’ injuries due to contact with the vent-holes), some AIS 2+ injuries did occur. These were almost exclusively fractures to the forearm that occurred due to direct contact with the airbag at the moment of deployment. Such injuries are considered in more detail in the discussion.

Table 7.
Contact sources for injury

Source of Injury	Airbag cases (n-= 253)		Non airbag cases (n=130)	
	All AIS	AIS 2+	All AIS	AIS 2+
Seat belts	44%	10%	47%	18%
Airbag	28%	3%	Nil	nil
Instrument panel	22%	6%	22%	9%
Steering assembly	13%	6%	16%	10%
Deceleration	12%	1.5	15%	6%
Floor and toe pan	9%	5%	9%	5%
Front screen and header	3%	nil	2%	1%
Side window and frame	2%	0.5	2%	1%
Doors and fittings	2%	1.5%	2%	1%
A pillar	1%	0.5%	Nil	nil
Roof side rail	1%	nil	Nil	nil
B-pillar	0.5%	nil	Nil	nil
Roof surface	nil	nil	1%	1%
Exterior other object/car	nil	Nil	1.5%	1.5%
Other contact	0.5%	Nil	1%	1%

DISCUSSION

Generally this study has found that airbags as Supplementary Restraint Systems (SRS's) work effectively to prevent injuries to several body regions. Injury reductions were observed particularly in respect of the head, face neck and chest although a trade-off in some respects has been an increase in injuries to the upper extremity at both the AIS1+ and AIS2+ level. The most notable difference in injury outcomes was observed when comparing injuries to the neck. Generally speaking, injuries to the neck in this study were 'whiplash' type injuries. It was encouraging to find that airbags do offer some degree of protection with respect to neck injury outcome since as has been reported elsewhere (e.g. Morris and Thomas, 1996, 1997) [10;11], whiplash injuries occur frequently in frontal impacts and can result in long-term if not permanent consequences to the afflicted (Kullgren, 1998) [12]. If airbags are indeed preventing 'whiplash' type injuries, as this study would suggest, then this is a very positive if somewhat unexpected finding. This also has some implications for neck injury research as it indicates that hyperflexion should not be over-looked as a neck injury mechanism whereas hyperextension (as occurs in rear impacts) is more frequently considered as the mechanism which is more likely to generate impairing neck injury.

Reductions in head and face injury through action of the deploying airbag are as laboratory crash-tests involving dummies predict. However, it is encouraging that such results are manifest in the real world where the carefully controlled laboratory conditions (e.g. 48.3 km/h into a rigid barrier) are rarely if ever met. Under more or less extreme conditions which have been observed in the real-world in this study, driver airbags are quite clearly offering protection to the driver.

One particularly reassuring aspect of this study is that airbags in Australia do not cause life-threatening injuries. This is in contrast to other studies, particularly in North America, where serious injury and even death have been caused by the deploying airbag. This is largely attributable to the fact that airbags in Australia are not the primary restraint mechanism as they are in North America. Therefore, the less aggressive, more benign systems in Australia are more suited to driver protection providing that the seat-belt is worn. One possible exception that has been observed in this study is that of injuries to the upper extremity. In many respects, contact between the deploying airbag and the upper extremity is unavoidable because the upper extremity will nearly always be in the proximity of the airbag when it deploys. However, if prevention of upper extremity injuries is to be achieved, then some benefit might be attained by reference to the study by McKendrew et al (1998) [13] which found that by padding the airbag led to a reduction in upper extremity fractures in cadaveric subjects. However, it should be observed that some upper extremity injuries are also caused by 'fling' of the upper extremity during airbag deployment into the A-pillar and roof rail, and this has been observed in other studies of injury outcomes in airbag vehicles.

The issue of Harm has been included in this study since this is a convincing means by which to evaluate the capability of airbags. Assuming that the cost calculations involved in Harm calculations accurately reflect the real cost in terms of injury consequence, then it is clear that savings in terms of injury costs are achieved through airbag deployments. A follow-up study in Australia which takes into account mass data rather than the sample that have been used in this study would be beneficial in further evaluations of cost-effectivenss in terms of Harm reduction.
There were some interesting findings in this study in terms of injury contact sources. Clearly the airbag prevents some of the more serious (AIS2+) injuries that can be generated through interaction of the driver with the seat-belt. Such injuries generally involve fractures of the ribs, sternum and clavicle. This suggests that the airbag exerts restraining forces on the occupant torso in a manner which is perhaps not well understood but where limitations of the load concentration of the seat belt as well as retarding excursion of the head/neck are achieved. It should not be overlooked that seat belt technology has also improved in recent times coincidental with the introduction of airbag technology. This study has not allowed for an evaluation of advanced belt technology such as pretensioners but follow-up studies are planned.

In conclusion this study found that the fitting of airbags into vehicles as a result of the ADR 69 ruling has reduced the number of injuries and injury costs to Australian drivers and society.

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